Aura TES team

# Validation of AIRS-based $HDO/H_2O$

## Comparisons with EVS-2 ORACLES measurements

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# AIRS HDO

## Outline

1. Motivation
2. Terminology
3. MUSES Retrieval
4. Delta-D Comparisons


# 1. Motivation

# Why are water isotopes important?

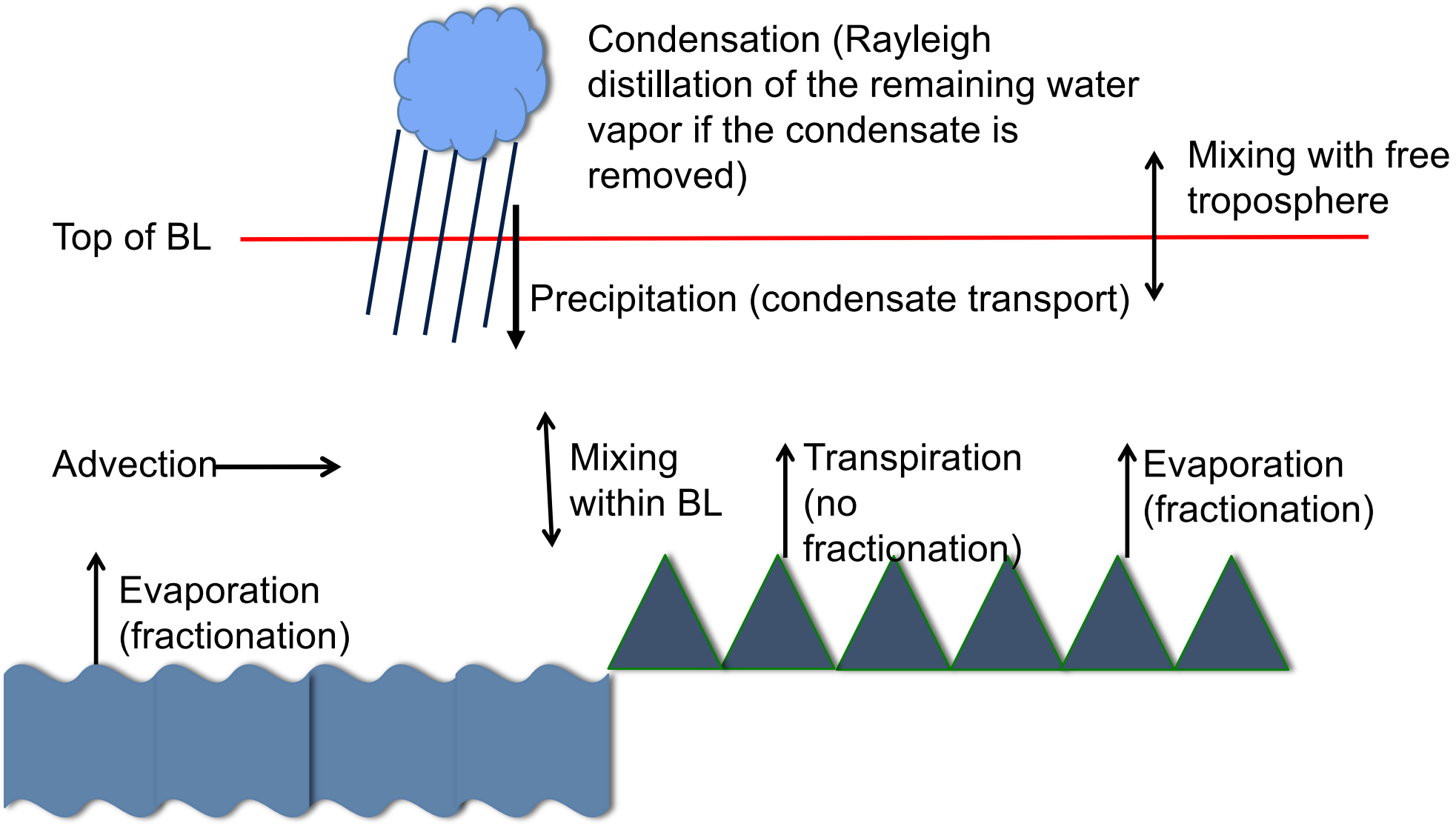
Water isotopes provide useful information about the hydrological cycle, including:

- The overall intensity of the hydrological cycle.
- Transport and mixing processes in the atmosphere.
- Moisture sources (e.g. local vs distant, convection vs evapotranspiration).

Spaceborne instruments that measure isotopes of water vapor, such as TES and AIRS, provide **regional** constraints on the hydrological cycle. The isotopic abundance in tropospheric water vapor is significantly different from the isotopic abundance in precipitation, so remote sensing provides a **unique** tool. Water isotopic measurements from TES have improved our understanding of the water budget in:

- Tropics [Worden et al., 2007]
- Hawaii [e.g. Noone et al., 2011]
- Amazon rainforest [Brown et al., 2008]
- Asian and North Australian monsoon [e.g., Brown et al., 2008; Lee et al., 2012]

# Processes that affect tropospheric water isotopic abundance



# Introduction to Water Isotopologues

- Water has several stable isotopologues. Most abundant are (in order) $H_2O$, HDO, $H_2{}^{18}O$.
- Evaporation and condensation are fractionating processes, with heavier isotopologues in the condensed phase.
- Removal of precipitation separates the heavier isotopologues from the gas phase, leaving increasingly depleted $HDO/H_2O$ in the gas phase.

# 2. Terminology

# Definitions

*Isotopes*: elements differing only in the number of neutrons,

Hydrogen H, Deuterium D = $^{2}H$, Tritium T = $^{3}H$.

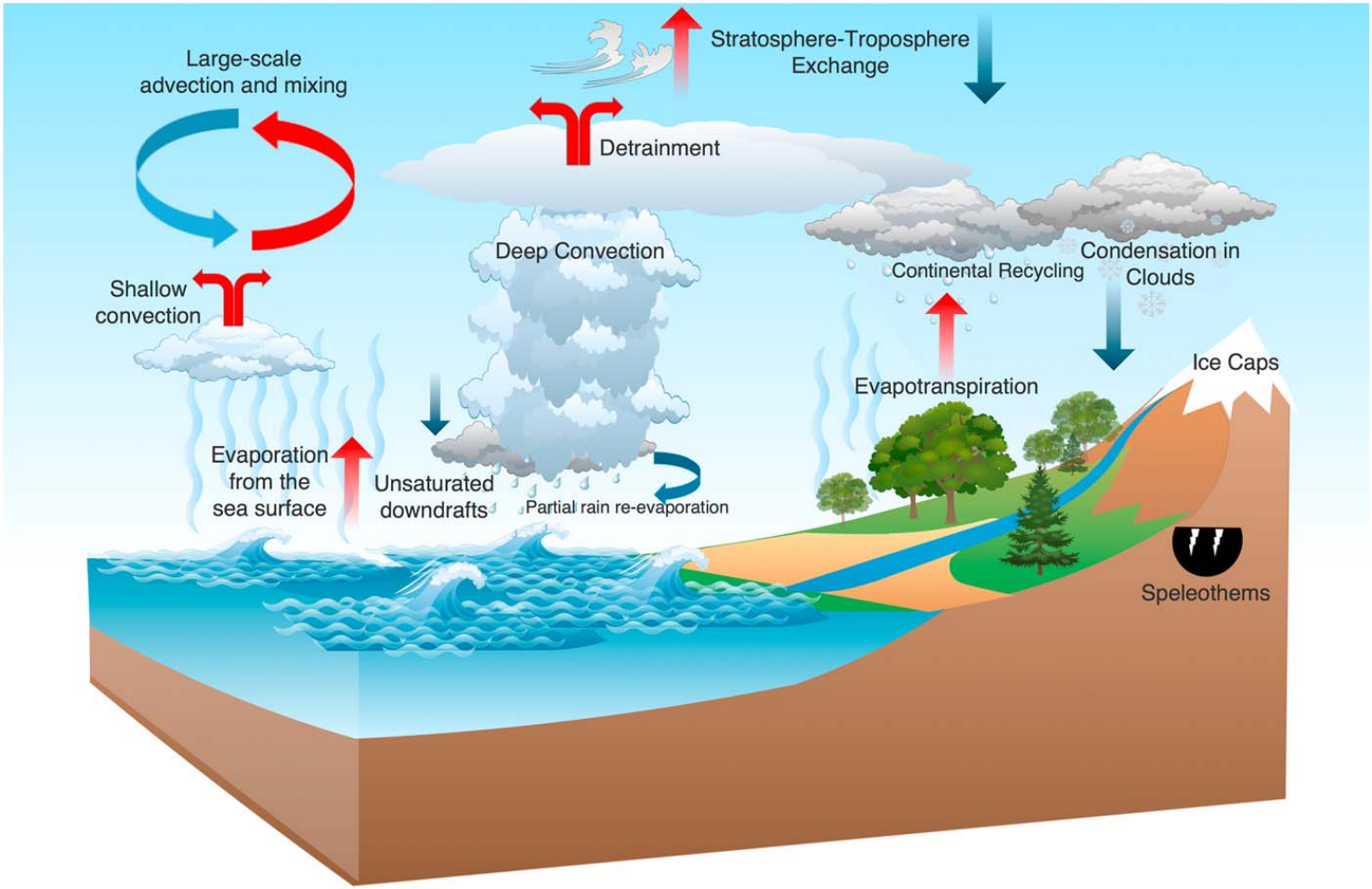
*Isotopologues*: molecules differing in isotopic composition, e.g., $H_2O$ versus HDO. These have slightly different physical properties, including molecular weight (18 versus 19) and vapor pressure.

*Fractionation:* a physical process that slightly *enriches* or depletes one isotopologue relative to another isotopologue. Condensation and evaporation of water isotopologues are fractionating processes, with HDO preferentially in the condensed phase. The fractionation factor increases at lower temperature.

*Delta notation:* $\delta D_{sample} = [(HDO/H_2O)_{sample}/(HDO/H_2O)_{SMOW} - 1]*10^3$ where SMOW is the reference "Standard Mean Ocean Water".

$(HDO/H_2O)_{SMOW} = 3.1152x10^{-4}$

**How water vapor isotopes help evaluate hydrological processes**
**Galewsky et al. Rev Geo. 2015**




Red arrows describe ”enriching” process

Blue arrows describe “depleting” process

Lighter isotopes of water preferentially evaporate. Heavier isotopes preferentially condense. Different moisture sources have different isotopic composition

Tropical Transpiration ~-65 to 0 per mil
Tropical Ocean Source ~-65 to -120 per mil
Tropical bare soil ~ -240 to -180 per mil

1) Quantifying rainfall evaporation in tropical monsoons (Worden et al., Nature 2007)
2) Partitioning transpiration and river run-off (Good et al., Science 2015)
3) Amazon transpiration initiates rainy season (Wright et al., PNAS 2017)


# 3. MUSES Retrieval

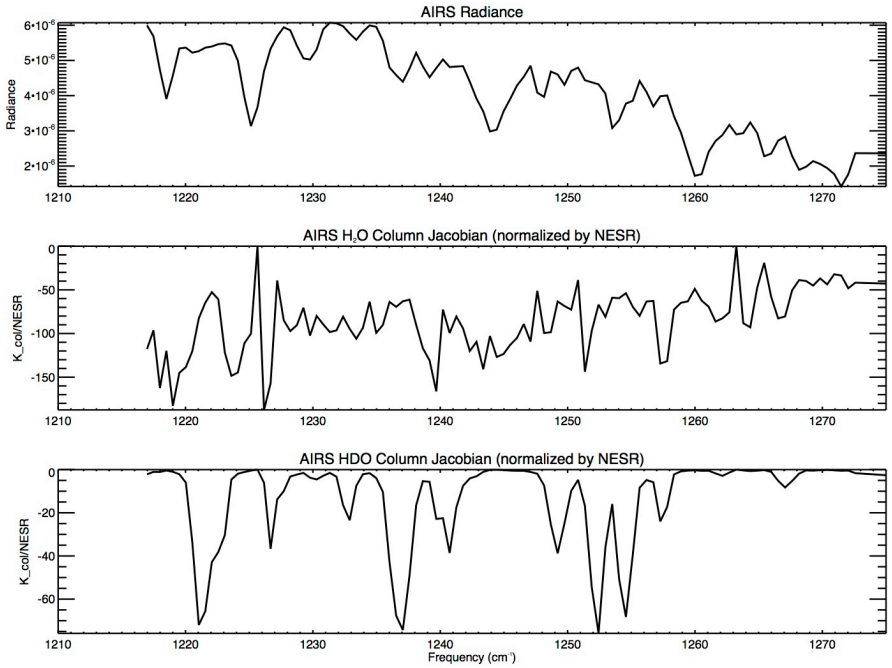
# MUSES Retrieval

To extend the record of TES, this work presents a multispectral approach that will provide HDO/$H_2O$ data products retrieved from single-footprint thermal infrared (TIR) hyperspectral radiances from AIRS.

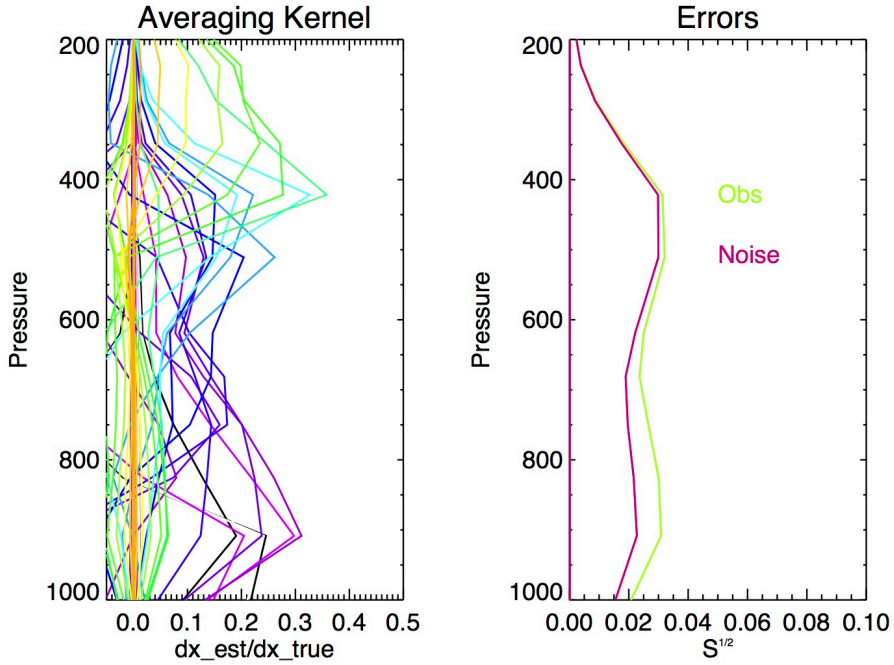
The retrievals are processed through the MUlti-SpEctra, MUlti-SpEcies, MUlti-SEnsors (MUSES) retrieval algorithm [Dejian Fu et al., 2018, and John Worden, subm.].

# AIRS HDO/$H_2O$ retrievals: averaging kernels and error (right)

**The MUSES team uses AIRS radiances from ~650 to 1340 $cm^{-1}$ (excluding the ozone band). Shown here are radiances and Jacobians near 8 microns where radiances are strongly sensitive to HDO:**

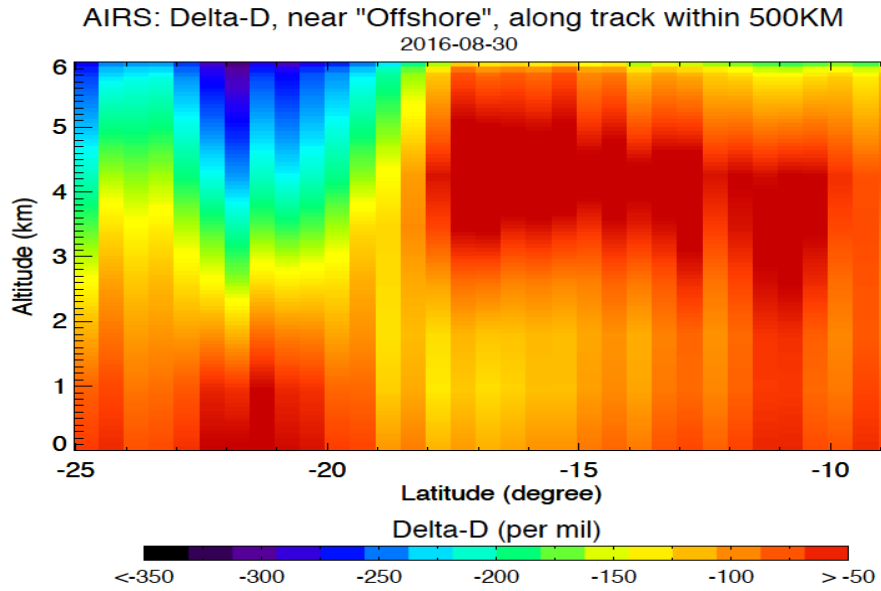


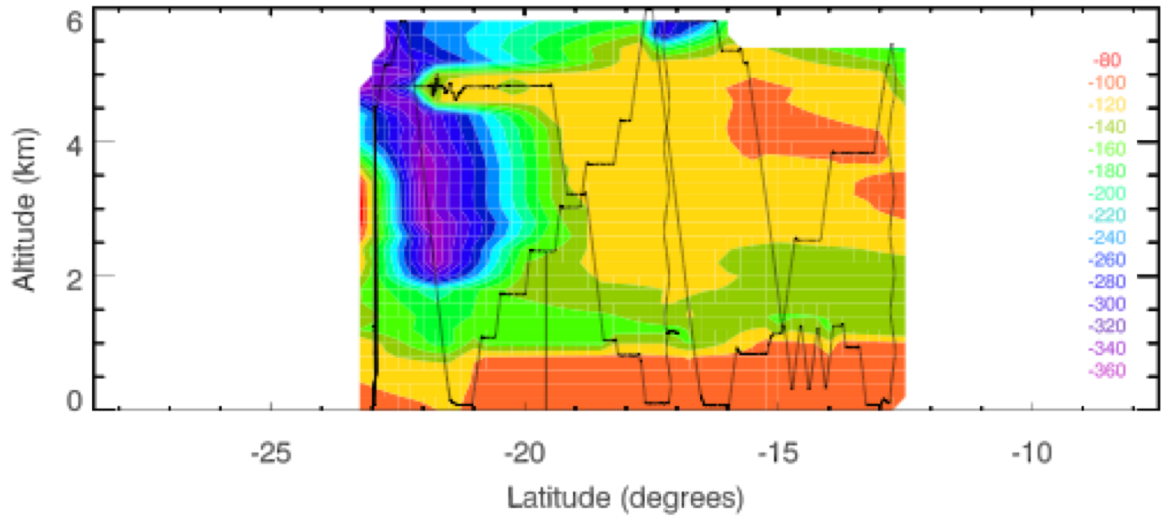

**AIRS tropical HDO/H2O estimates have ~1.5 DOFS and ~20 per mil error**



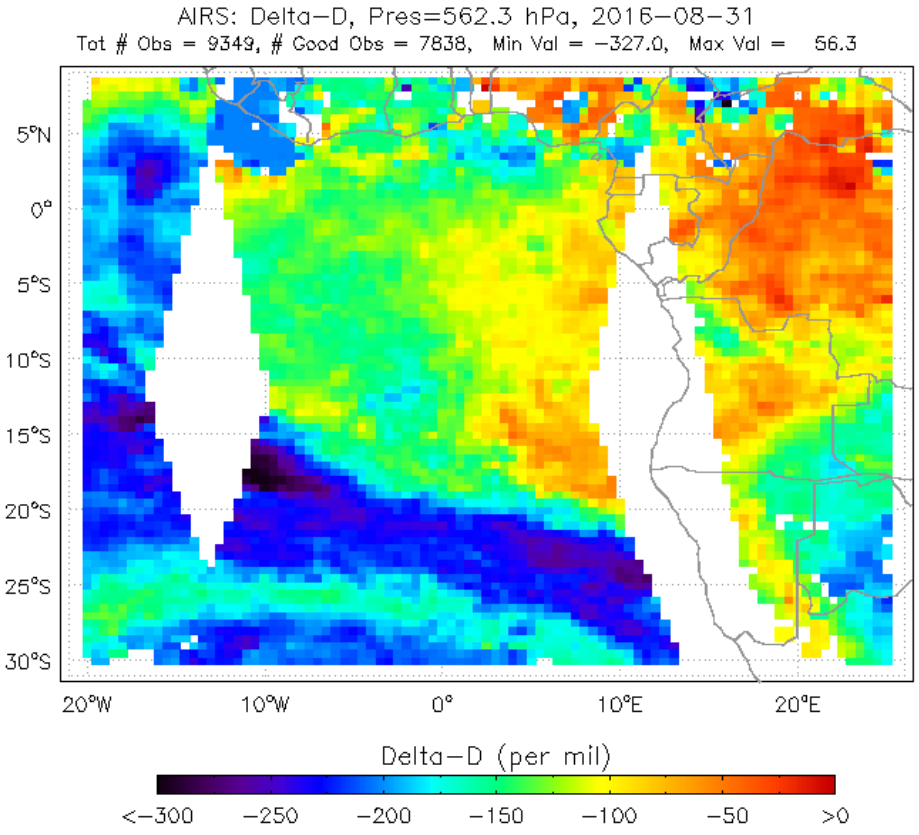
# 4. Delta-D Comparisons

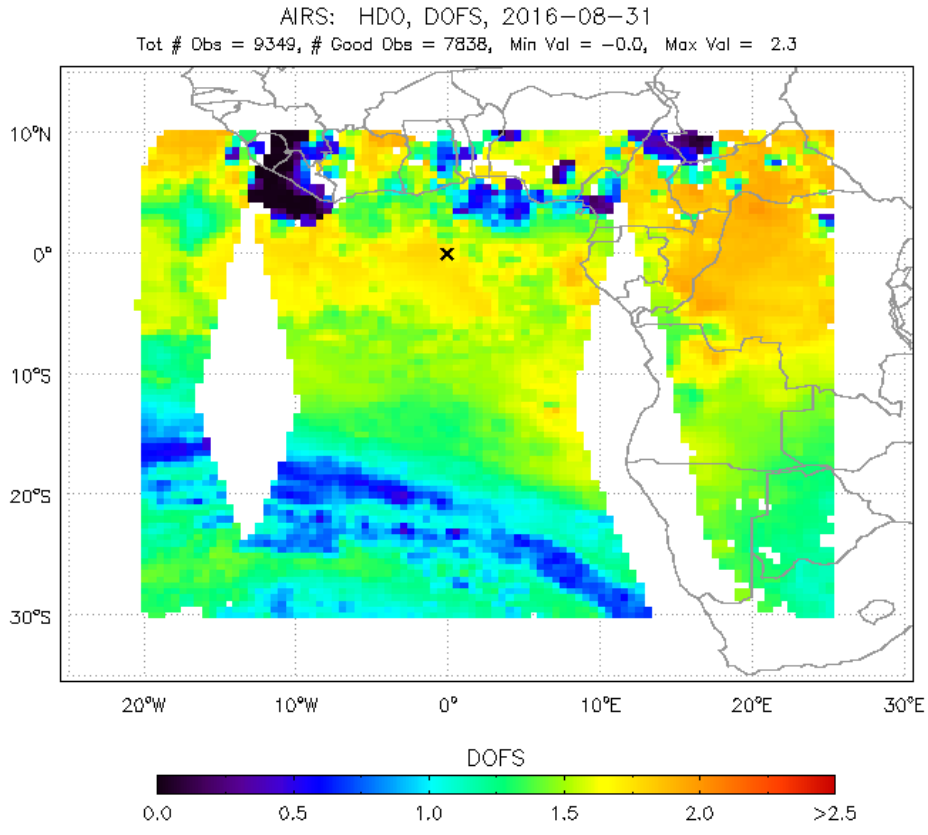
# AIRS comparisons with ORACLES



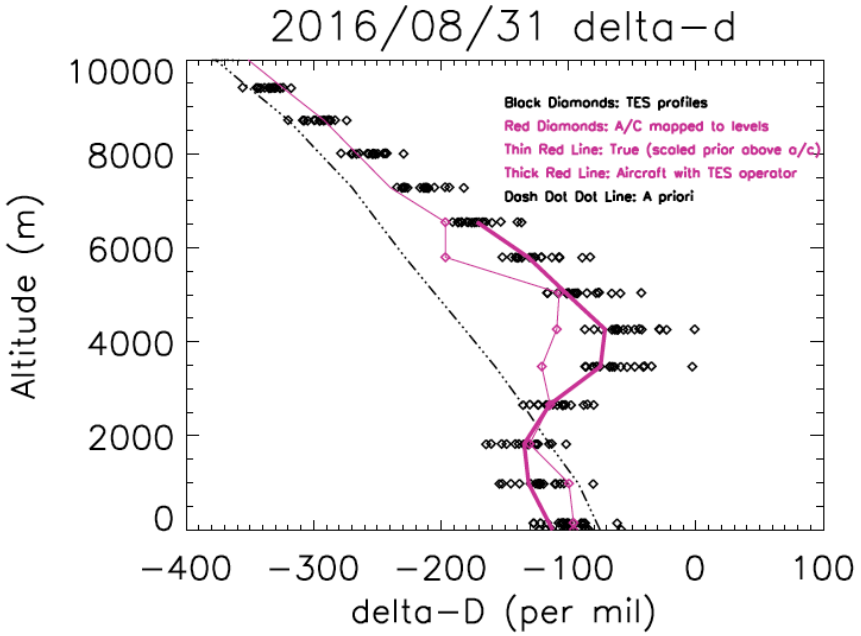



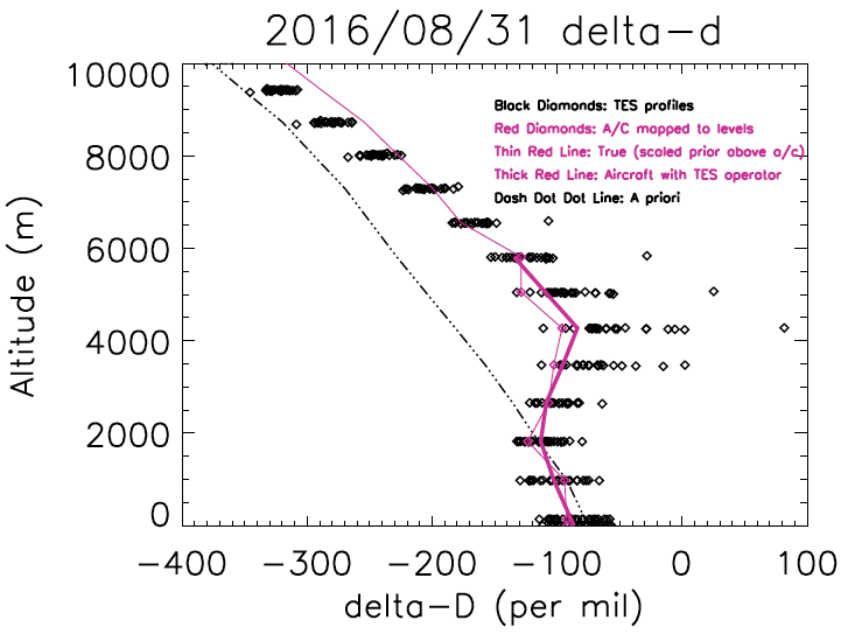
# AIRS Delta-D retrievals over Southeast Atlantic, 8-31-2016

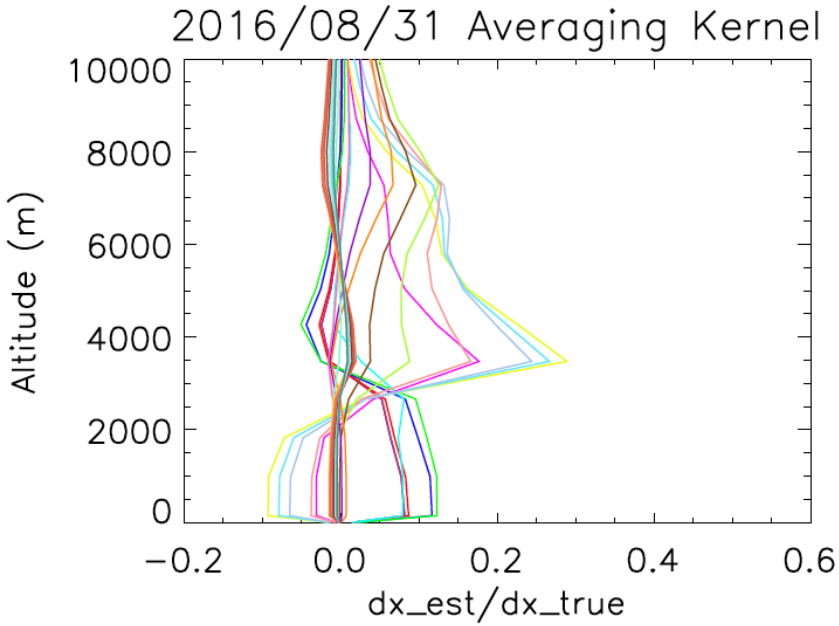


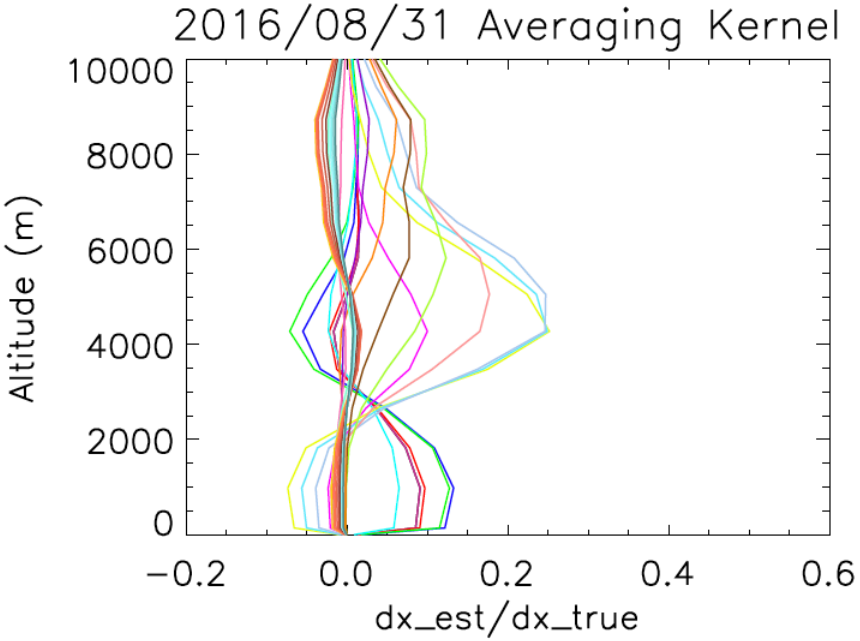



# AIRS versus ORACLES aircraft



**Summary:**
AIRS HDO/H2O retrievals are very well characterized ~1.5 DOFS and 25 per mil uncertainty

Agreement is excellent with TES (average mean difference is < 3 per mil over TES record)

Data Production is progressing very well.

Exciting science possibilities with ORACLES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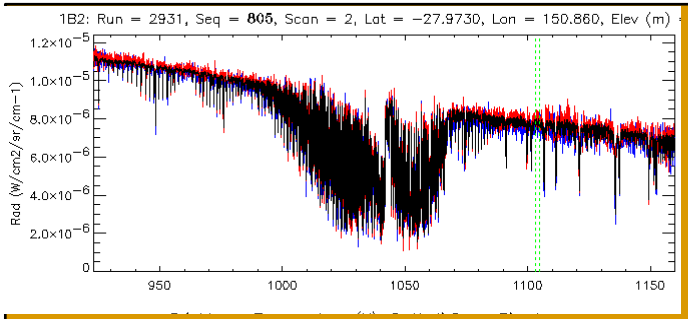
# AIRS

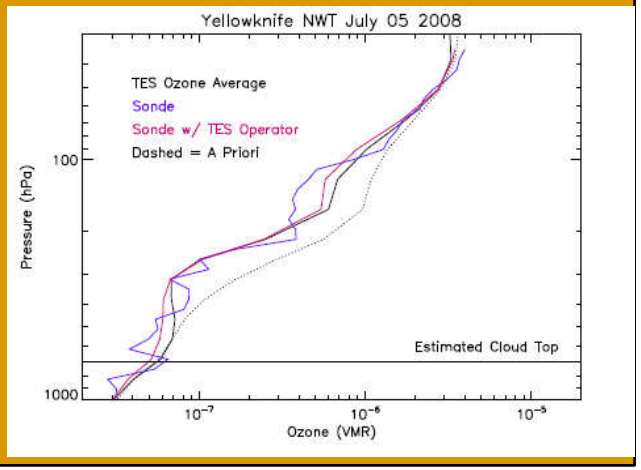
- backup slides

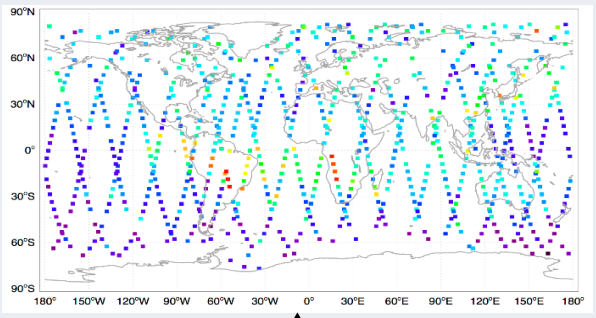
# How do we turn measured top-of-atmosphere radiances to profiles of composition?



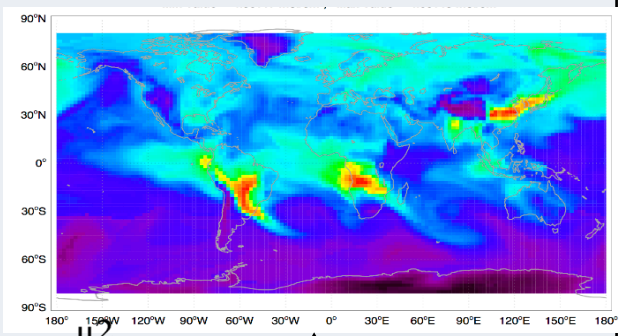

$$\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\|^2_{\mathbf{S}_n^{-1}}+\|\mathbf{x}-\mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$$

$$\hat{\mathbf{x}}=\mathbf{x}_a+\mathbf{A}(\mathbf{x}-\mathbf{x}_a)+\mathbf{Gn}$$




$$\mathbf{H}(\mathbf{x})=\mathbf{x_a}+\mathbf{A}(\mathbf{x}-\mathbf{x_a})$$

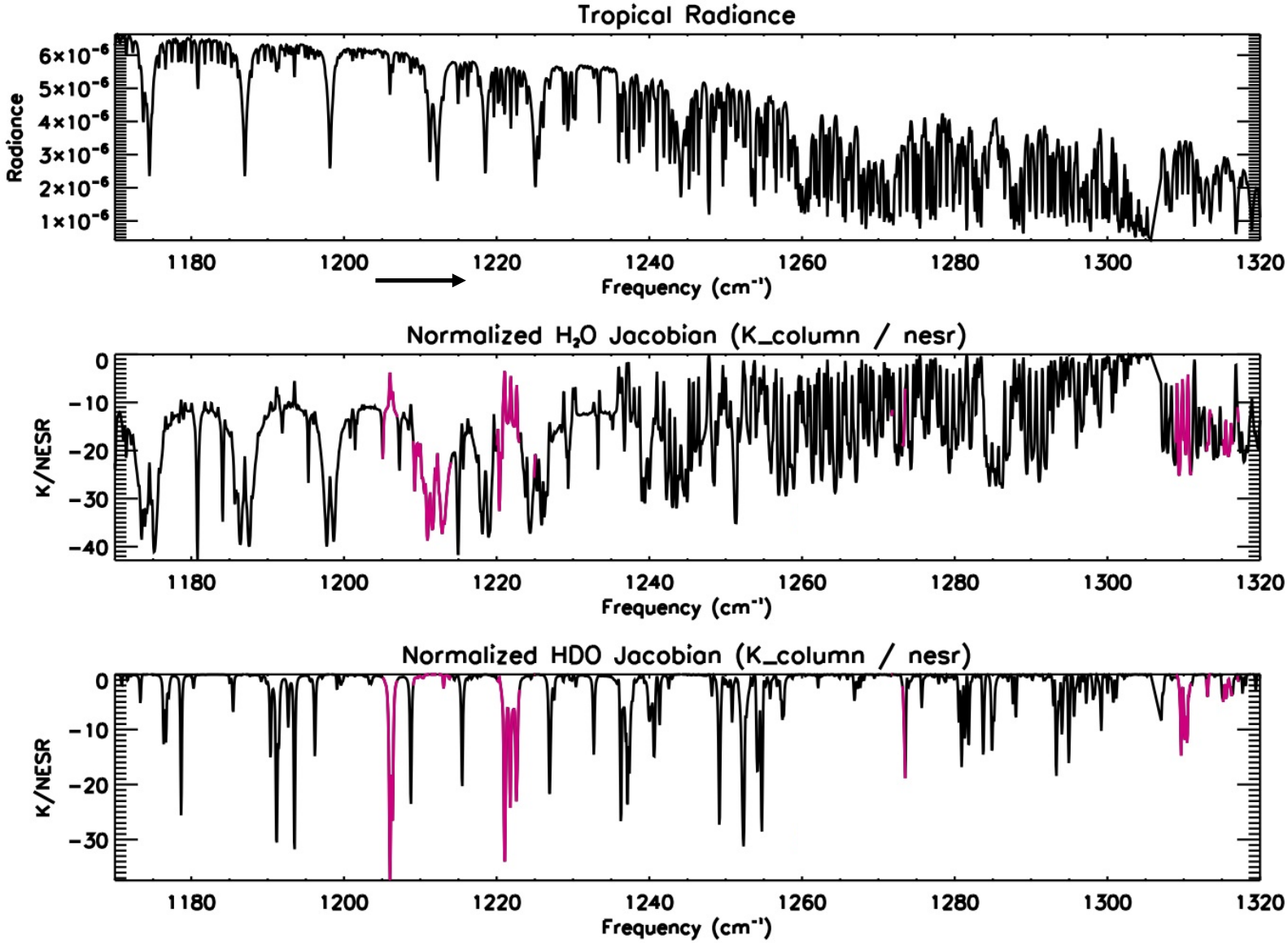



$$\sum_i \|\hat{\mathbf{x}}_i-\mathbf{H}_i(\mathbf{x})\|^2_{(\mathbf{G}_i\mathbf{S}_n^i\mathbf{G}_i^T)^{-1}}+\|\mathbf{x}_0-\mathbf{x}_B\|^2_{\mathbf{B}^{-1}}$$

**Optimal estimation provides the error characterization and averaging kernels needed to test uncertainties and use data with models**

# Overview of TES HDO/H2O retrievals (1)

## TES Radiance and Sensitivity to HDO and $H_2O$




Scale:
0 to -40

# Overview of TES HDO/H2O retrievals (2)